Electron Cooler for Low-Energy RHIC Operation

January 28, 2010

Meeting agenda

- Baseline approach
- Work scope and goals
- Electron beam simulations

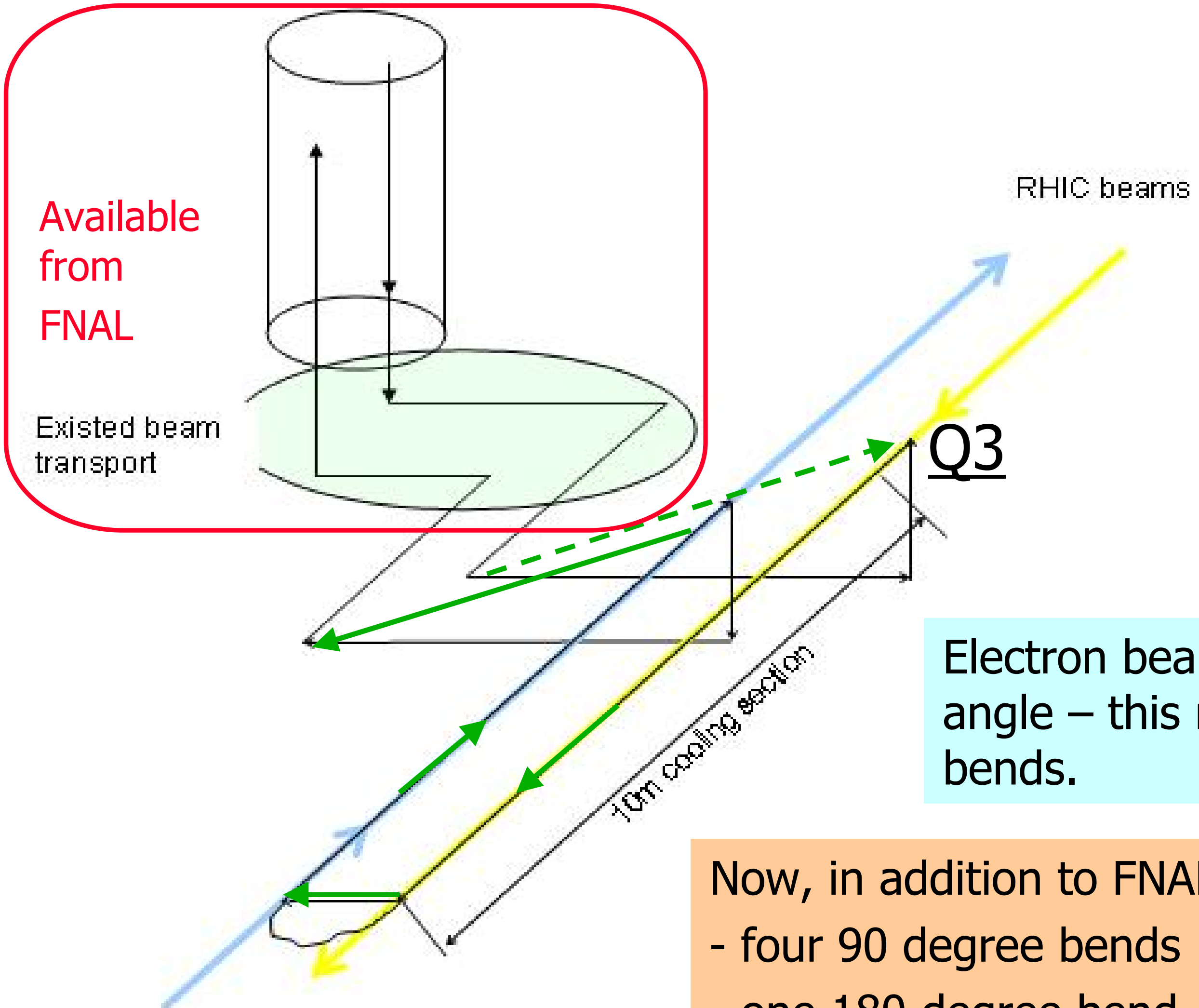
Baseline parameters

1. FNAL's cooling section "as is" – with solenoids, correctors, etc.

(to prevent over focusing from ion beam)

2. Cooling section beam pipe size – 3″ OD (S.T. is looking into RHIC optics).
3. BPM's design for 3″ OD pipe (2.87″ID)– using FNAL's design
4. Electron beam transport under one ion beam line with an angle towards other ion beam line.
5. Blockhouse @ IR4: inside cryo-lines.

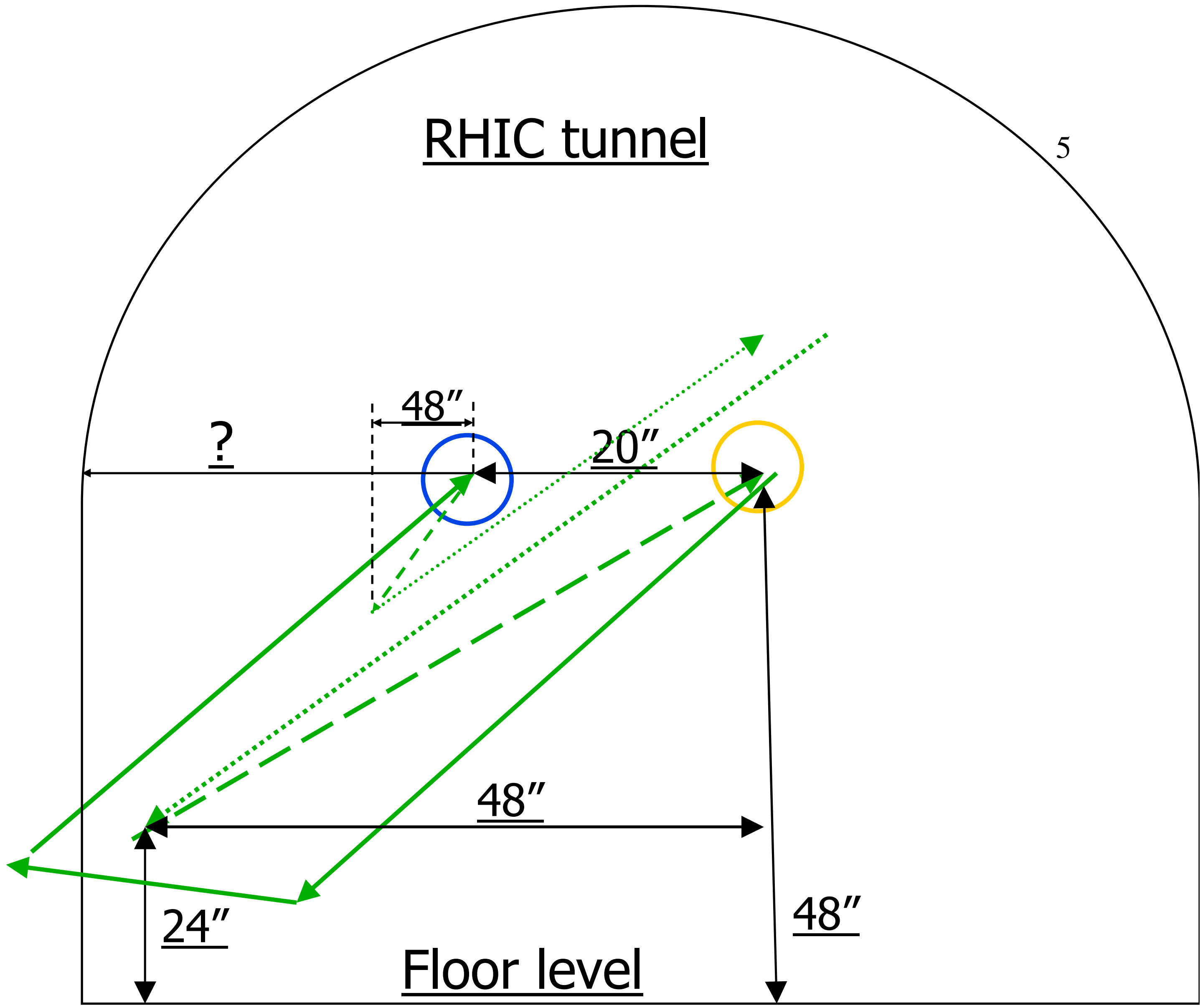
Presently@IR4:



Electron beam is tilted at an angle – this removes two 90 deg. bends.

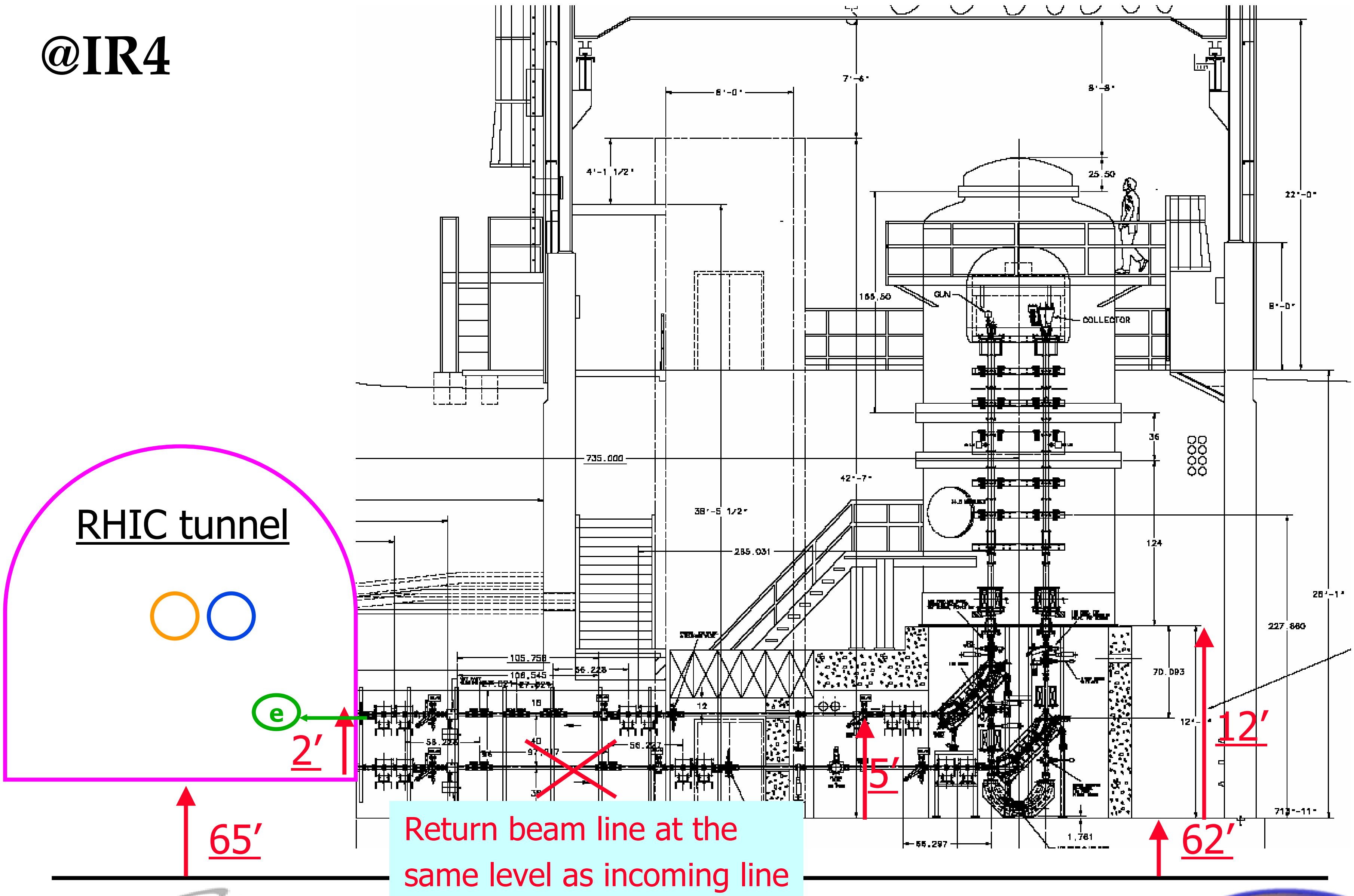
Now, in addition to FNAL bends, we have:

- four 90 degree bends
- one 180 degree bend



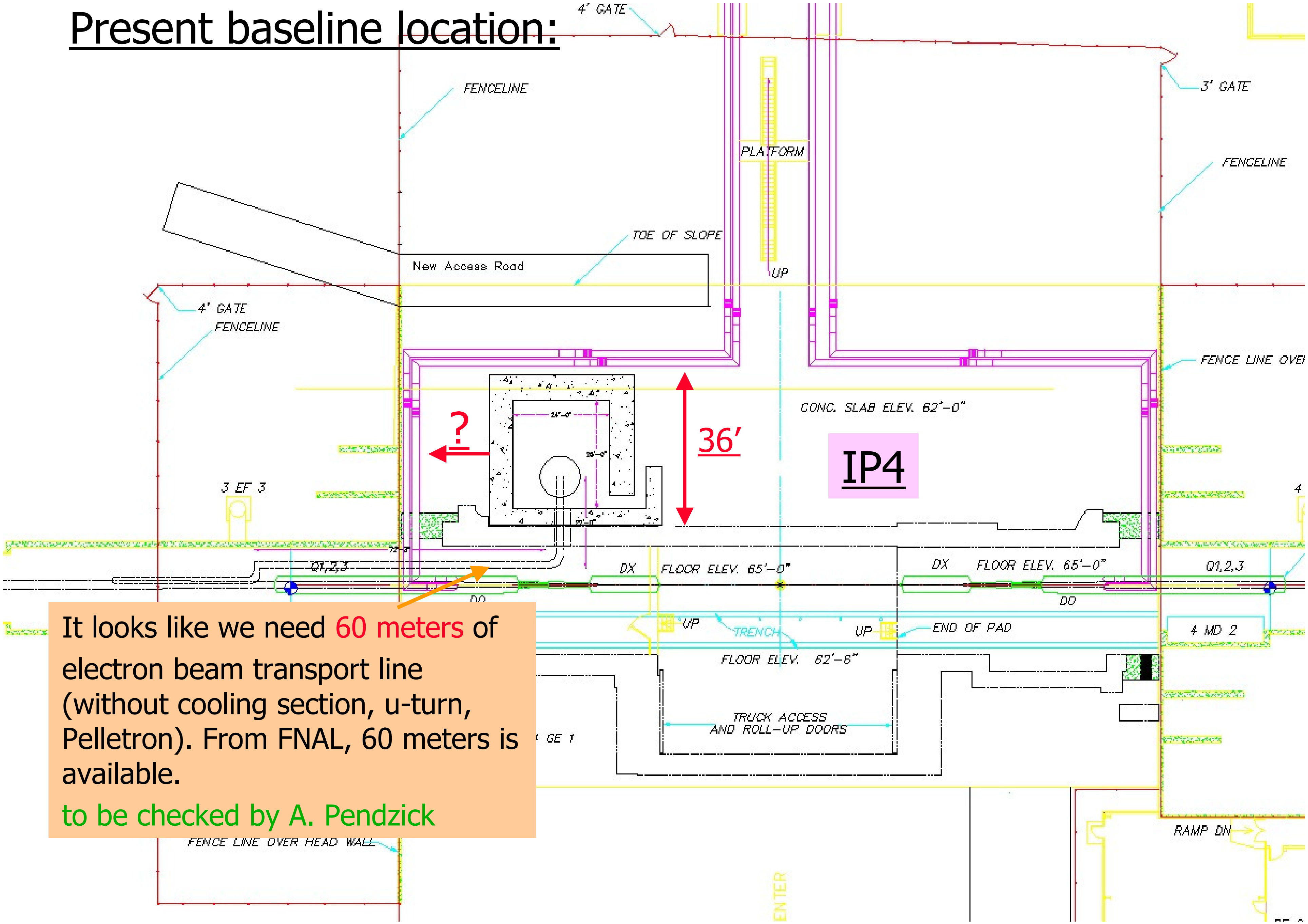
RHIC tunnel
48″
?
20″
48″
24″
48″
Floor level

@IR4



RHIC tunnel
e
2′
65′
5′
12′
62′
Return beam line at the same level as incoming line
GUN
COLLECTOR
8'-0"
7'-6"
8'-8"
4'-1 1/2"
25.50
22'-0"
8'-0"
166.50
735.000
42'-7"
38'-5 1/2"
285.031
36
124
28'-1"
227.660
70.093
105.758
106.545
56.228
58.227
56.227
55.297
1.761
713'-11"

Present baseline location:



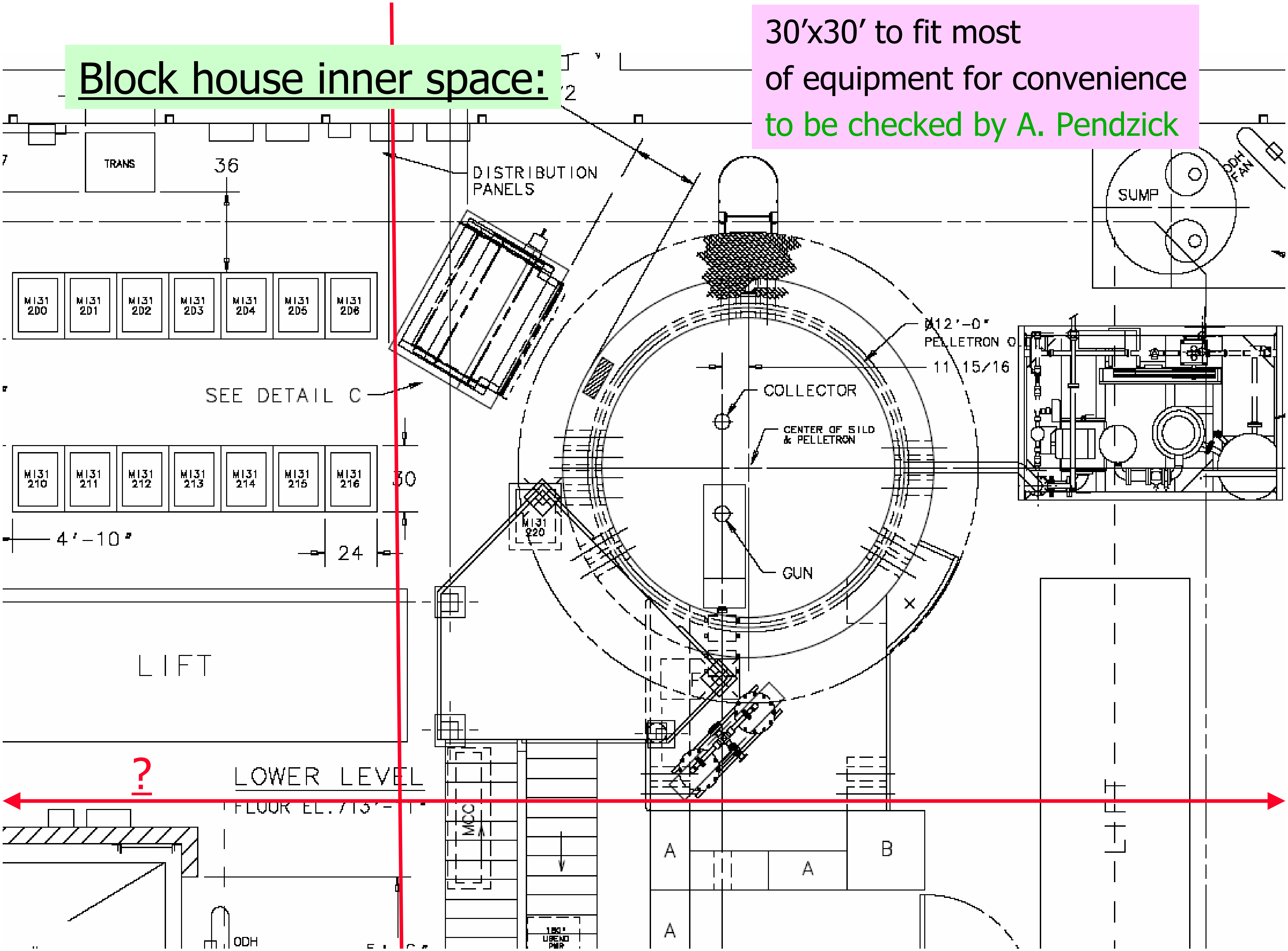
It looks like we need 60 meters of electron beam transport line (without cooling section, u-turn, Pelletron). From FNAL, 60 meters is available.

to be checked by A. Pendzick

Block house inner space:

30’x30’ to fit most of equipment for convenience

to be checked by A. Pendzick



RHIC Electron Cooler parameters

Present baseline approach:

"Non-magnetized" – means no strong magnetic field to guide electron beam and in cooling section. But small field can be used to provide need electron angles in cooling section.

- "as is" - present FNAL's set-up with small magnetic field on the cathode (100G) and in cooling section (100G) (+ undulators).

Electron kinetic energy, MeV	0.9-2.8 (4.9)
DC current, mA	50-100
RMS momentum spread	< 0.0004
RMS transverse angles, mrad	< 0.2
?Undulator field B_u, G	3
?Undulator period: λ_u, cm	8
Length of cooling section L_{cool} per ring, m	10

Near-term goals

FY10:

- **Start regular physics and engineering meetings**
- **Choose location in RHIC tunnel**
- **Choose one design (with or without solenoids)**
- **Decide about undulators**
- **Design realistic beam transport**
- **Design appropriate bending magnets**
- **Address many physics and engineering questions**
- **Start architectural design**
- **Start electrical design**
- **Start mechanical design**

Summer 2010 – collaboration (FNAL) review?

Around December 2010: - formal agreement between BNL and FNAL; decision how to proceed before spending AIP funds

December 2010 – design review?

January 2011: start AIP project (AIP funds in FY11, FY12, FY13)

Aggressive schedule which requires significant C-AD manpower support starting FY11.

Preliminary cost estimate of the project –	November 2009 (done)
Estimate of C-AD manpower	November 2009 (done)
Physics design complete	December 2010
Architectural design & layout	February 2010-February 2011
Electrical design & layout –	June 2010-June 2011
Mechanical design & layout –	June 2010-June 2011
Site preparation –	February 2011- March 2012 (14 month)
Recycler's cooler disassembly and transport	October 2011-February 2012 (5 month)
Electron cooler installation	March 2012 –January 2013 (10 month)
Commissioning	February-July 2013 (6 month)

Available for FY14 RHIC physics run – November 2013.

-2014 run: should expect luminosity optimization (partial improvement)

-starting 2015 – expect full luminosity improvement

PROJECTION OF C-AD MANPOWER NEEDED FOR LOW-E RHIC ELECTRON COOLING 11/03/09

Year	Work scope	Manpower	Hours	Comments
FY10	**Design & layout**			
	Architectural	Engineer	1056	1 person/50% of time/1year
		Designer	528	
	Electrical	Engineer	176x3	3p/10%/1y
		Designer	132	
	Mechanical	Engineer	176x3	3p/10%/1y
		Designer	528	
	Instrumentation		176	to evaluate what is available, needed
	Controls		176	to evaluate what is needed
	Additional magnets	Engineer	200	
		Designer	300	
		Physicist	4100	about 2 FTE + other support
FY11	**Design & layout**			
	Electrical	Engineer	176x3	3p/10%/1y
		Designer	132	
	Mechanical	Engineer	176x3	3p/10%/1y
		Designer	528	
	Instrumentation		704x2	Estimates for diagnostics can be done during FY10. As such, FY11-FY13 numbers in this table are arbitrary until more firm estimates.
	Cooling section	Engineer	200	
		Designer	200	
	Site preparation	Engineer	520	
		Designer	70	
		Assigned	640	
		DTS	160	
		Physicist	4100	about 2 FTE + other support

FY12	**Disassembly &**	Engineer	528	The rest is assigned/to be paid to
	Transport	Technician	240	FNAL (additional 8000hours), which
	Installation	DTS	336	is included in cost estimate
	Vacuum system	Engineer	120	
		Designer	180	
	Instrumentation		1056x2	
	Controls		2800	Presently, numbers for controls are based on hardware complexity (no
				bottoms up estimate done yet).
				Accurate estimate will be done later.
	Assembly	Technician	2760	Some of needed labor is already
		Assigned	200	included in cost estimate, including
		DTS	380	up to 5520 hours paid to FNAL+NEC
		Physicist	4100	
FY13	**Installation &Commissioning**	Engineer	320	Project engineer
	Vacuum system	Technician	178	
		Engineer	120	
	Instrumentation		2000	
	Controls		2800	Assumes that most of present software
				will need to be rewritten
		Technician	2760	+FNAL+NEC help, which is included
		Assigned	200	in cost estimate
		DTS	380	
	Several people	Engineer	1760	help from Tandem?
	Working in shifts	Physicist	3520	+possible FNAL experts

<u>Most C-AD manpower will be needed in FY12 & FY13</u>

Near-term milestones

By June 2010:

1. Accurate cost estimate and manpower from controls
2. Accurate cost estimate and manpower from instrumentation
3. Results from first Low-E Physics run
4. Results from beam dynamics limits at Low-E RHIC

June-July 2010:

1. Updated luminosity projection with cooling
2. Updated cost of the project
3. Review of the above and decisions

Start of Architectural, Mechanical, Electrical design can be probably delayed until about July 2010 without overall impact on project end date.

Delay of start of AIP project beyond January 2011 may result in delay of luminosity improvement with cooling beyond 2015 which does not justify the project.

NICA program, etc.

Major "near-term" tasks

1. Transport of electron beam at lower energies; design of bending magnets; evaluating needed control of field quality (X. Chang)
2. Design of turn around (U-turn) of electron beam between cooling sections. Checking preservation of electron beam quality with additional bends, lowest energy (X. Chang, D. Kayran, J. Brodowski)
3. Electron cooler optics. Electron beam (X. Chang, D. Kayran)
4. Ion beam optics for cooling section (S. Tepikian)
5. Careful consideration of "angular budget" in the cooling section from various effects in full energy range of interest (A. Fedotov)
6. Interaction of electron and ion beams.
7. Undulators "to be or not to be?" (A. Fedotov)
8. Cooling section and diagnostics.

E-beam dynamics simulations

FNAL used:

SAM code – to design and simulated beam through the gun

OptiM code – to simulate beam optics (accurate treatment of coupling, analytic KV approximation for space charge)

- **we do not need to redesign the gun.**
- **we can start beam dynamics simulation with known e-beam distribution**
- **First task is to set-up lattice similar to FNAL's and check whether we can use PARMELA for this (vs. OptiM).**
- **Ultimate goal is to simulate beam dynamics at lowest energies of interest and design an appropriate beam transport.**

FNAL cooler: Optical Requirements

- Pbar optics is fully described by the requirement to have cooler's beta-function as small as possible, i. e. of 20-30 m (about the cooler length). While the cooling rates are rather weakly sensitive to the beta-function ($\propto \sqrt{\beta}$), the electron angle requirements are a tough issue: $\theta_e \cong \sqrt{\varepsilon_p / \beta}$.
- Electron beam is angular momentum dominated [3]. This means that its effective emittance is determined by the magnetic field at the cathode, while the temperature is irrelevant. Such beams have a sharp transverse boundary.
- Electron optics has to satisfy the following requirements:
  - Parallel and round e-beam of radius 4-6 mm in the cooler;
  - No dispersion in the cooler, small or zero dispersion in the accelerator;
  - Envelope maximums are limited to avoid nonlinear aberrations - half-axes ~ 1 cm upstream of the cooler;
  - Preferably no flips of the angular momentum - to reduce the Touschek effect;
  - Round and well-focused beam in the deceleration section.

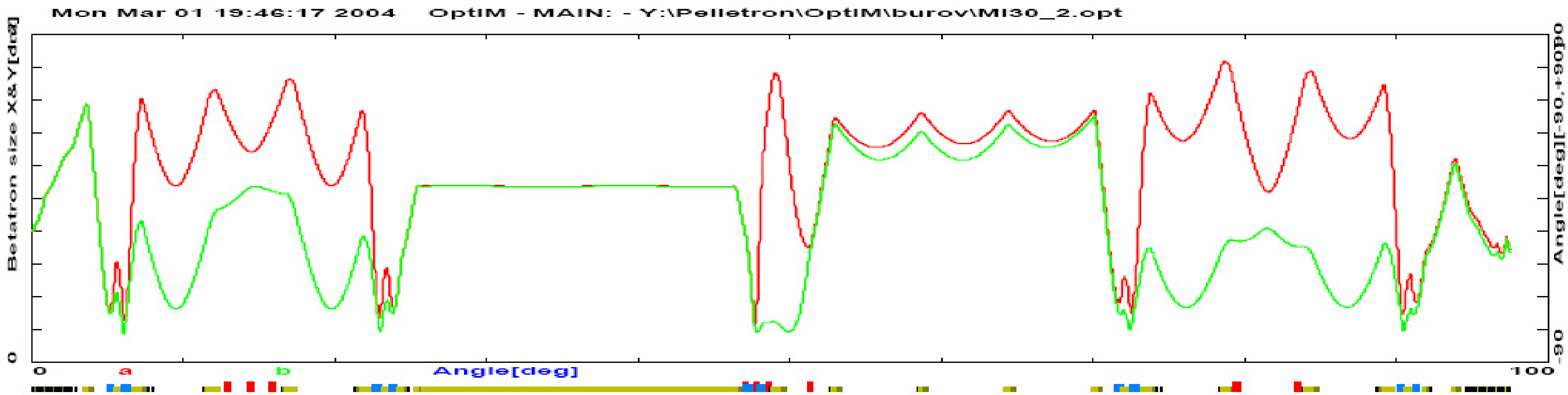
Electron Beam in the Cooler

- Properties of the e-beam in the cooler follows from a requirement to optimize the cooling process.
  - Electron angles have to be smaller than angles of "tail" antiprotons. This sets a limit on the r. m. s. electron angles in the cooler $\theta_e \le (2-3)\sqrt{\varepsilon_p / \beta}$. If this condition is not satisfied, the cooling rates are reduced as $1/\theta_e^3$.
  - Electron beam has to cover "tail" antiprotons. This means that it has to be round with the radius $a_e \cong (2-3)\sqrt{\varepsilon_p \beta}$.
  - The beam have to be focused to suppress space charge, ions and image charge perturbations.
- All this requires magnetic field in the cooler $B_{cooler} \cong 50-100$ G .
- The generalized Busch's theorem [3] leads to a requirement of the magnetic field at the cathode, matched with the field at the cooler by the flux preservation:

$$Ba_e^2\Big|_{cooler} = Ba_e^2\Big|_{cathode}$$

Beam Envelope

- Figure shows design envelope of the cooler made with the OptiM code [5]. Due to the angular momentum domination, the beam boundary is well-defined.
  - The beam is round in the accelerating tube.
  - The invariance is broken at the first 90° bend.
  - The invariance is restored after the second 90° bend, and the beam is round again in the cooling section. It is also parallel here.
  - The invariance is broken by the dispersion-suppressing quad inside the U-bend and almost restored by a solenoidal dublet and a quad
  - The mirror symmetry of the transfer line restores the invariance
  - The beam is round in the deceleration section.
- Outside of the bends, dispersion is zeroed.



Rounding by lattice symmetry

- The beam is rounded in the cooler with all the upstream quads zeroed. This is possible due to the mirror symmetry of the supply lattice.